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Vela

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(54) **TUNABLE HIGH ISOLATION CIRCULATOR**

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***H01P 1/383*** (2006.01)

(52) **U.S. Cl.**
CPC ................ ***H01P 1/383*** (2013.01); ***H01P 1/36*** (2013.01)

(58) **Field of Classification Search**
CPC ...... H01P 1/32; H01P 1/36; H01P 1/38; H01P 1/383
USPC .................................................. 333/1.1, 24.2
See application file for complete search history.

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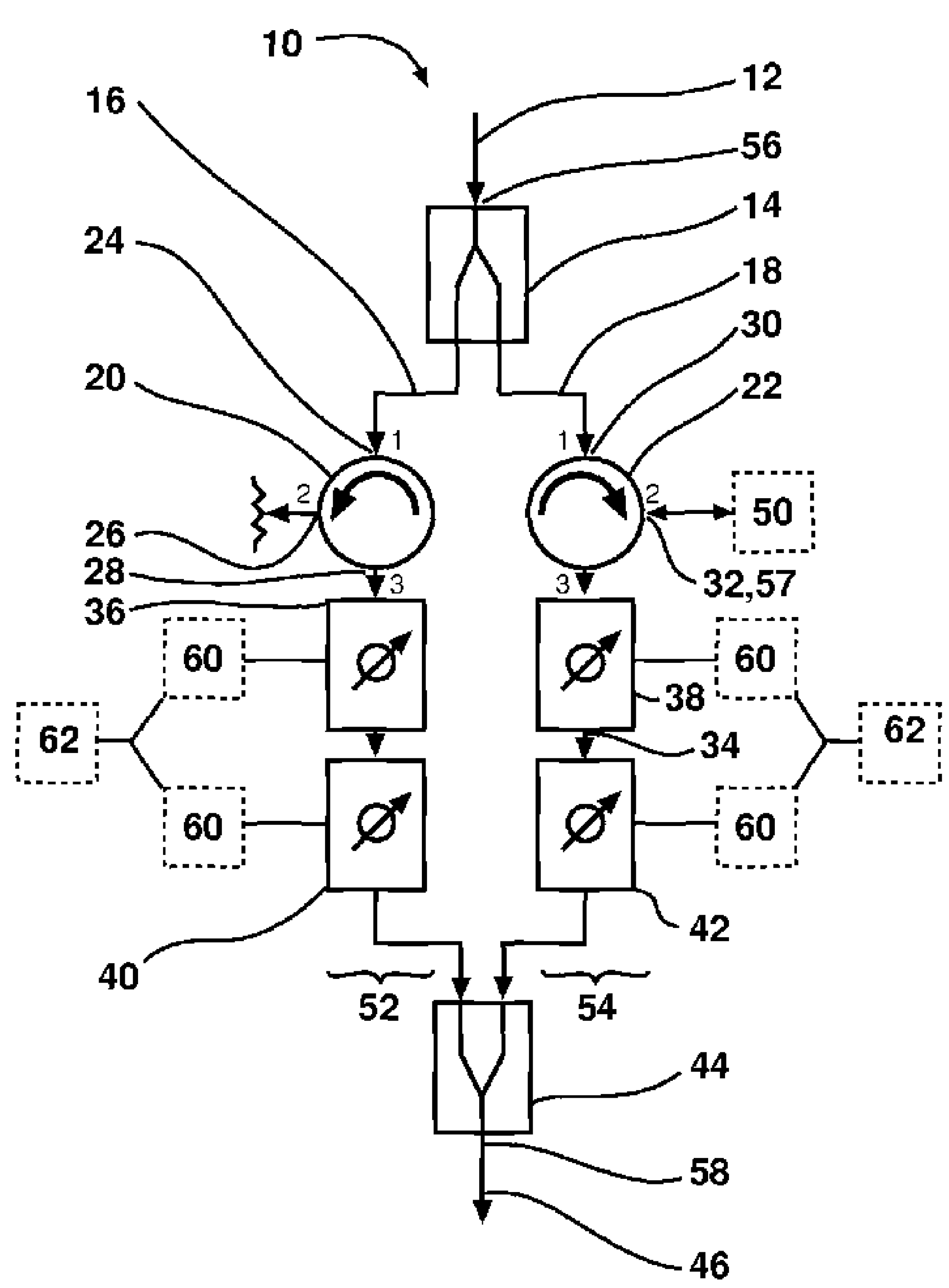
(57) **ABSTRACT**

A system for improving port isolation of a three port circulator device includes a power splitter having a power splitter input and two power splitter outputs. A first circulator has a first circulator first port, a first circulator second port, and a first circulator third port, and the first circulator first port is electrically coupled to the first of the two power splitter outputs. A second circulator has a second circulator first port, a second circulator second port, and a second circulator third port, and the second circulator first port is electrically coupled to the second of the two power splitter outputs. A first trimmer is electrically coupled to the first circulator third port and a second trimmer is electrically coupled to the second circulator third port. The system further includes a power combiner having two power combiner inputs and one power combiner output, and the first of the two power combiner inputs is electrically coupled to the first trimmer and the second of the two power combiner inputs is electrically coupled to the second trimmer.

**9 Claims, 2 Drawing Sheets**



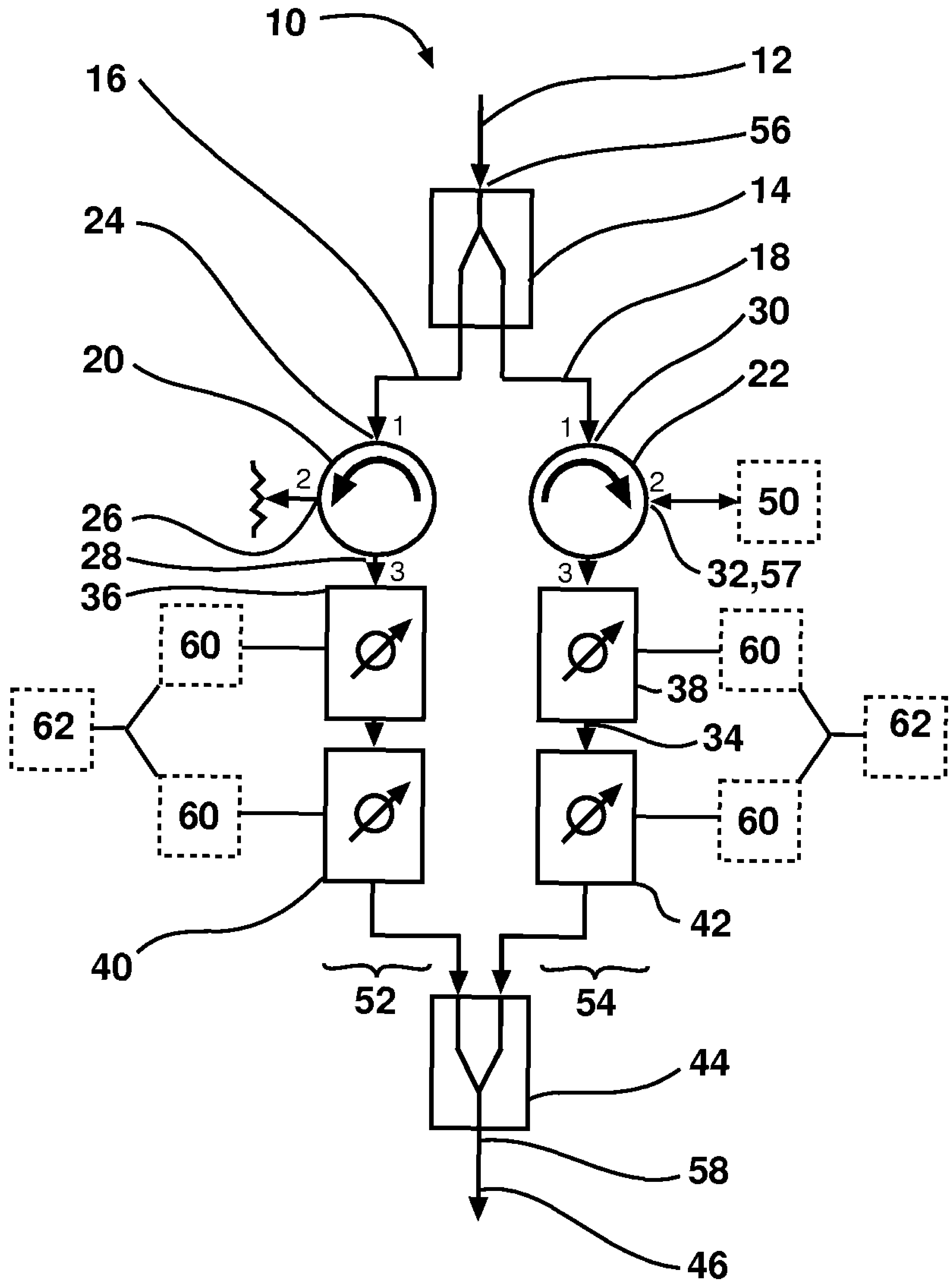

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Fig. 1

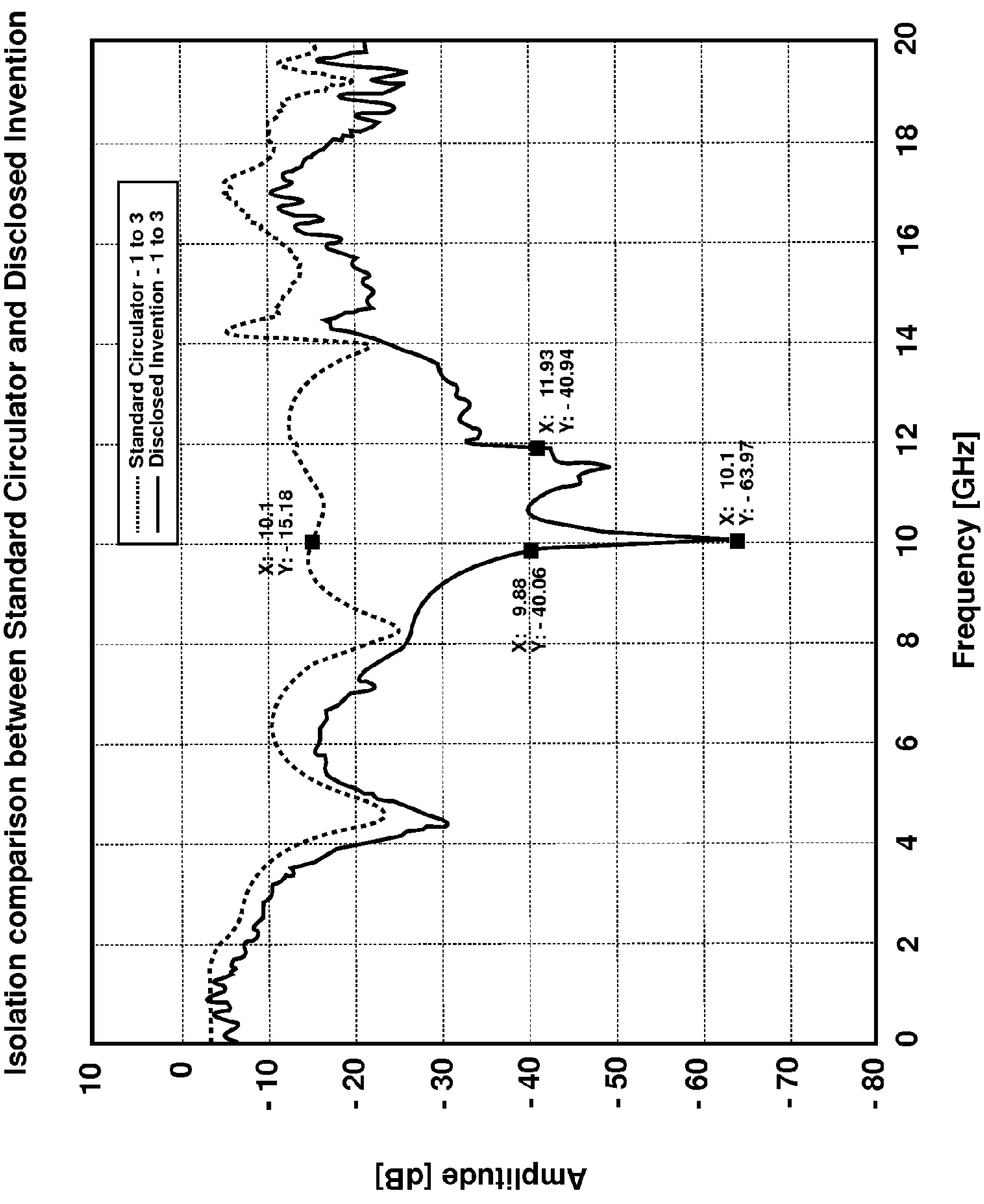
Isolation comparison between Standard Circulator and Disclosed Invention
Standard Circulator - 1 to 3
Disclosed Invention - 1 to 3
X: 10.1
Y: - 15.18
X: 9.88
Y: - 40.06
X: 10.1
Y: - 63.97
X: 11.93
Y: - 40.94
Amplitude [dB]
Frequency [GHz]
10
0
- 10
- 20
- 30
- 40
- 50
- 60
- 70
- 80
0
2
4
6
8
10
12
14
16
18
20

Fig. 2

# TUNABLE HIGH ISOLATION CIRCULATOR

## RIGHTS OF THE GOVERNMENT

The invention described herein may be manufactured and used by or for the Government of the United States for all governmental purposes without the payment of any royalty.

## FIELD OF THE INVENTION

The present invention relates generally to radio frequency signal processing and, more particularly, to enhanced port isolation in systems using microwave circulators.

## BACKGROUND OF THE INVENTION

An RF junction circulator, duplexer, or T/R switch (or, as will be used in the discussion that follows, a "circulator") is a three-port device formed by a symmetrical Y junction coupled to magnetically biased ferrite material. Coaxial based components may utilize substrate material for the conductive path of the signal, and the ferrite element to divert the fields between ports. The circulator permits the flow of microwave energy in one direction only, e.g. from port **1** to **2**, **2** to **3**, and **3** to **1**. When one of the ports is terminated with a load under a matched configuration, the other two are isolated in the reverse direction. Thus, an isolator is a circulator which has a matched termination, usually integral to the unit, on port **3**.

In these devices, port **1** would be considered the "input" port, **2** would be the input or output port, depending on the application or mode, and **3** would be the output port. For example, in a traditional radar configuration, port **1** is connected to a transmitter, port **2** to the antenna, and port **3** to the receive architecture. In operation, the transmit pulse would propagate from port **1** to port **2**; the received signal from the antenna would then go from port **2** to port **3**.

Unfortunately, port **1** and port **3** are not completely isolated from one another, thus contributing to leakage into port **3**. This leakage of the transmit signal results in degradation in performance of the overall system, as the minimum detectable received signal should be above the leakage signal. If leakage between ports **1** and **3** is reduced, however, the attenuated noise would allow for a cleaner signal from port **2** to be observed at port **3**. By way of example, it would enhance minimum detectable ranges of signals, or targets, in radar applications. Additionally, such noise reduction can enable higher achievable dynamic ranges in microwave receiver architectures. From a communications perspective, this would allow reception of even weaker signals in devices which both transmit and receive simultaneously.

Known methods of attenuating undesired internal reflections are either only moderately effective, or operate in a less effective digital, post-analog-processing, regime. As a result, there exists a need in the art for improved systems and methods to reduce or eliminate leakage signals and undesirable internal reflections in microwave circulators.

## SUMMARY OF THE INVENTION

The present invention overcomes the foregoing problems and other shortcomings, drawbacks, and challenges of reducing undesirable reflections and interference in microwave systems. While the invention will be described in connection with certain embodiments, it will be understood that the invention is not limited to these embodiments. To the contrary, this invention includes all alternatives, modifica-



tions, and equivalents as may be included within the spirit and scope of the present invention.

According to one embodiment of the present invention, a system for improving port isolation of a three port circulator device is provided. The system includes a power splitter having a power splitter input and two power splitter outputs. A first circulator has a first circulator first port, a first circulator second port, and a first circulator third port, and the first circulator first port is electrically coupled to the first of the two power splitter outputs. A second circulator has a second circulator first port, a second circulator second port, and a second circulator third port, and the second circulator first port is electrically coupled to the second of the two power splitter outputs. A first trimmer is electrically coupled to the first circulator third port and a second trimmer is electrically coupled to the second circulator third port. The system further includes a power combiner having two power combiner inputs and one power combiner output, and the first of the two power combiner inputs is electrically coupled to the first trimmer and the second of the two power combiner inputs is electrically coupled to the second trimmer.

According to another embodiment of the disclosed invention, in a system including a power splitter having a power splitter input and two power splitter outputs; a first circulator having a first circulator first port, a first circulator second port, and a first circulator third port, wherein the first circulator first port is electrically coupled to the first of the two power splitter outputs; a second circulator having a second circulator first port, a second circulator second port, and a second circulator third port, wherein the second circulator first port is electrically coupled to the second of the two power splitter outputs; a first trimmer electrically coupled to the first circulator third port and a second trimmer electrically coupled to the second circulator third port; and a power combiner having two power combiner inputs and one power combiner output, wherein the first of the two power combiner inputs is electrically coupled to the first trimmer and the second of the two power combiner inputs is electrically coupled to the second trimmer; a method for adjusting the first trimmer and the second trimmer to yield improved port isolation is provided. The method includes terminating a matching impedance fixed load and test load to the first circulator second port and the second circulator second port, respectively. The method further includes terminating test instrumentation at the power combiner output. A desired frequency signal is injected into the input of the power splitter. The strength of the signal at the power combiner output is observed. Either of the first trimmer or the second trimmer is adjusted to yield an attenuated desired frequency signal. The strength of the attenuated desired frequency signal is observed.

Additional objects, advantages, and novel features of the invention will be set forth in part in the description which follows, and in part will become apparent to those skilled in the art upon examination of the following or may be leaned by practice of the invention. The objects and advantages of the invention may be realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

## BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the present invention and, together with a general description of the invention given above, and the detailed description of the embodiments given below, serve to explain the principles of the present invention.

FIG. **1** is a schematic view of a microwave reflection reducing system in accordance with embodiments of the disclosed invention.

FIG. **2** is a graph demonstrating the enhanced reflection isolation of the disclosed system as compared to a traditional circulator.

It should be understood that the appended drawings are not necessarily to scale, presenting a somewhat simplified representation of various features illustrative of the basic principles of the invention. The specific design features of the sequence of operations as disclosed herein, including, for example, specific dimensions, orientations, locations, and shapes of various illustrated components, will be determined in part by the particular intended application and use environment. Certain features of the illustrated embodiments have been enlarged or distorted relative to others to facilitate visualization and clear understanding. In particular, thin features may be thickened, for example, for clarity or illustration.

## DETAILED DESCRIPTION OF THE INVENTION

The following discussion will disclose systems and methods to enhance performance in three port circulator applications. By way of example, the disclosure relates to systems for canceling impedance mismatch reflections from port two of a circulator, in addition to enhancing isolation between ports one and three. Further, the disclosed systems will be directed to cancellation of reflections from port two to port one to port three, as well as optimizing signal purity from port two to port three. Unexpectedly high performance will be demonstrated by comparing the roughly −25 dB isolation values of known circulators with the approximately −70 dB values realized by the disclosed and claimed system.

Turning attention to FIG. **1**, the system **10** receives an input signal **12** and sends it to a power splitter **14**. The power splitter **14** divides the input signal **12** into a first path **16** and a second path **18**. The input signal **12** of the first path **16** and the second path **18** travel to a quasi-identical first circulator **20** and second circulator **22**.

The circulators **20** and **22** are described as quasi-identical because even circulators of the same model and batch will include variability introduced in the manufacturing process. The placement or orientation of internal ferromagnetic materials, tuning performed by the factory technician, variations in materials, etc. will all impact the performance and characteristics of the circulator in a quantifiable way. In the system **10** that follows, enhanced performance will be achieved if circulators **20** and **22** are selected to minimize such variables to the extent possible. Selected circulators **20** and **22** should be of the same model number, same batch, and preferably close in serial number to each other. Further, a plurality of similar serial numbered devices may be profiled on a network analyzer to select a pair of circulators **20** and **22** having the closet performance characteristics. Performance characteristics, include, but are not limited to, voltage standing wave ratio (VSWR), insertion loss, isolation, operational frequency range, impedance, and power handling capability.

First circulator port one **24** and second circulator port one **30** are coupled to the power splitter **14**, and first circulator port three **28** and second circulator port three **34** are coupled to a first phase trimmer **36** and second phase trimmer **38**, respectively. A third phase trimmer **40** and fourth phase trimmer **42** may be coupled in series to the first phase trimmer **36** and second phase trimmer **38**, respectively, to provide enhanced adjustment as will be described below.

The outputs of the first phase trimmer **36** and second phase trimmer **38** (or outputs of the third phase trimmer **40** and fourth phase trimmer **40**, if employed), terminate into a power combiner **44**. After tuning and configuration (as will be explained in detail below) the system **10** will behave analogous to (with significantly enhanced isolation and reflection reduction) a traditional circulator.

According to embodiments of the disclosed invention, the system **10** may be tuned to center the highest isolation at a desired frequency. During tuning, second terminal port two **32** of the invention may be "loaded" or matched to a similar impedance load at first circulator port two **26** (e.g., if the first circulator second port **26** fixed load is matched to 50Ω then the test load **50** should also be 50Ω). Once the resistor, or test load **50**, is attached, the output signal **46** should be connected to a device which allows the operator to observe the frequency response (e.g., spectrum analyzer, network analyzer, etc.). Once connected to suitable monitoring instrumentation, the desired frequency is injected into the power splitter **14** (which in turn is conveyed to first circulator port one **24** and second circulator port one **30**). It should be noted that "load" attached to port **26** of circulator **20**, influences the performance of the overall invention. As such, to optimize the matching to the load on port **2** of **22**, an impedance matching network can also be utilized instead of a fix load. This ability to "tune" the impedance will allow the invention to meet a wider assortment of needs within the community.

As will be recognized by one of ordinary skill in the art, the desired central frequency should be within the operational frequency ranges of each of the components utilized in this system **10** (e.g., circulators **20** and **22**, power splitters **14**, power combiners **44**, phase trimmers **36**, **38**, **40**, and **42**, etc.). Acceptable results may be achieved if each of the phase trimmers **36**, **38**, **40**, and **42** are initially adjusted to their minimum values. With the desired signal injected, the phase trimmers **36**, **38**, **40**, and **42** of a single "channel", or leg, of the system **10** (e.g., trimmers **36** and **40** coupled to the first circulator **20** constitute a first channel **52**, while trimmers **38** and **42** coupled to second circulator **22** constitute a second channel **54**) are adjusted while observing the resultant output signal **46** on the spectrum analyzer or network analyzer.

Once the frequency of a channel **52** or **54** is sufficiently offset in phase, it will begin to destruct the opposing channel's signal. One should continue to adjust the phase trimmers **36**, **38**, **40**, and **42**, until the desired frequency of interest has reached its minimum value. Note that this technique can also be performed for wide bandwidth, and ultra wide bandwidth signals as well. In ultra wide bandwidth configurations, two regions will develop: a high isolation region (in some instances approaching 70 dB) with limited bandwidth, and larger bandwidth region of less, but still high isolation (in some instances approaching 50 dB).

While the above describes the general method for tuning the invention, the overall method can be automated, or computer controlled to ensure reproducibility. Microcontrollers, Field Programmable Gate Arrays (FPGAs), or Digital Signal Processors (DSPs), can be programmed to step through a series of routines which would control both the tuning of the phases shifters, as well as monitoring the frequency spectrum of **46**. This realtime feedback loop would provide an optimal method for production. Note that during this process, as the devices are analog in nature, digitization of the signal on **46** should utilize a high sampling rate analog to digital converter (ADC) as the precision of the digitizer would determine the precision, or depth, of the signal cancellation, and therefore spectral null.

Once maximum attenuation of the desired signal has been achieved on the spectrum analyzer, oscilloscope, or network analyzer, the internal reflections, and leakage between the two signal paths has been minimized. The load **50** is then removed from second circulator port two **32**. Once tuning is complete, the disclosed system **10** is ready to serve as a high isolation circulator, having a systemic port one **56** input, a systemic port two **57** output/input, and a systemic port three **58** output.

In some embodiments of the disclosed invention, the trimmers may be configured to allow manipulation by a cooperating servo, linear actuator, or the like (a trimmer tuner **60**). In some embodiments, the trimmer tuner **60** may be coupled to a rotary adjustable trimmer, while in other embodiments, sliding type trimmers may be coupled to an external adjustment mechanism. Phase trimmer examples vary, and include, but are not limited to, surface mount variations, connectorized and pre-packaged modules, in both digital and analog instantiations. Phase shifters, or trimmers, can also be derived by variable delay line techniques and are readily found in COTS such as those in the Data Delay Device's **1500** series, ELMEC Technology's VDA series, or the ADSANTEC ASNT series.

A controller **62** having a processor and memory, may be coupled to the trimmer tuners **60**. The controller **62** may be configured to generate and inject an appropriate input signal **12**, observe the resultant output signal **46**, and iteratively adjust each of the trimmers **36**, **38**, **40**, and **42** until maximum attenuation of the desired frequency is achieved. In some embodiments, the controller **62** is configured to adjust the trimmers **36**, **38**, **40**, and **42** until a minimum attenuation is achieved (e.g., at least −50 dB). In other embodiments, the controller **62** is configured to halt tuning and accept a sub-optimal attenuation after a selected period of time, a selected number of iterations, or upon exceeding other thresholds.

In further embodiments, the tuning is performed for a plurality of desired input signal **12** frequencies, and the acceptable tuning values are retained for each of the plurality of desired frequencies. For example, the controller **62** may perform tuning for each of 2 GHz, 10 GHz and 18 GHz. The tuning values, or relative positions of the trimmers **36**, **38**, **40**, and **42**, are retained by the controller **62** for future use. In some embodiments of the disclosed invention, the controller **62** may select appropriate tuning value for additional frequencies by interpolation or other approximation techniques. As a result, the system **10** can be reconfigured on the fly, in near-real time by the controller **62**, to be optimized for each of 2, 10, and 18 GHz.

It should be noted that the individual specifications of the components utilized in this system **10** yield the overall frequency and power boundaries. Design considerations will dictate the selected devices for the system **10** to ensure that the desired frequency, power, bandwidth, and insertion losses are achieved.

A note on the insertion loss of the device is also important to mention. In the configuration disclosed above, the highest individual component insertion loss is provided by the first power splitter **14** at systemic port one **56**. Low loss components should be selected to ensure that minimum insertion loss between systemic port one **56** and systemic port two **57** is achieved.

In use, significant isolation and reflection cancellation may be achieved by embodiments of the disclosed invention. Turning attention to FIG. **2**, embodiments of the disclosed invention yield unexpected circulator performance improvements across ultra wideband frequencies, and greater isolation at narrower bandwidths. The resultant graph was captured from an actual laboratory configuration. For purposes of comparison, the dotted graph represents the isolation performance of a standard circulator (best performance of approximately −25 dB). While the disclosed invention yielded an attenuation of −63 dB, attenuation approaching −70 dB has been observed by further refinement of the trimmer adjustments. It is further noted that improved attenuation of approximately −40 dB are shown over the bandwidth of approximately 10 to 12 GHz.

While the present invention has been illustrated by a description of one or more embodiments thereof and while these embodiments have been described in considerable detail, they are not intended to restrict or in any way limit the scope of the appended claims to such detail. Additional advantages and modifications will readily appear to those skilled in the art. The invention in its broader aspects is therefore not limited to the specific details, representative apparatus and method, and illustrative examples shown and described. Accordingly, departures may be made from such details without departing from the scope of the general inventive concept.

What is claimed is:

**1**. A system for improving port isolation of a three port circulator device, the system comprising:

a power splitter having a power splitter input and two power splitter outputs;

a first circulator having a first circulator first port, a first circulator second port, and a first circulator third port, wherein the first circulator first port is electrically coupled to the first of the two power splitter outputs;

a second circulator having a second circulator first port, a second circulator second port, and a second circulator third port, wherein the second circulator first port is electrically coupled to the second of the two power splitter outputs;

a first trimmer electrically coupled to the first circulator third port and a second trimmer electrically coupled to the second circulator third port;

a power combiner having two power combiner inputs and one power combiner output, wherein the first of the two power combiner inputs is electrically coupled to the first trimmer and the second of the two power combiner inputs is electrically coupled to the second trimmer; and

a third trimmer disposed between the first trimmer and the power combiner.

**2**. A system for improving port isolation of a three port circulator device, the system comprising:

a power splitter having a power splitter input and two power splitter outputs;

a first circulator having a first circulator first port, a first circulator second port, and a first circulator third port, wherein the first circulator first port is electrically coupled to the first of the two power splitter outputs;

a second circulator having a second circulator first port, a second circulator second port, and a second circulator third port, wherein the second circulator first port is electrically coupled to the second of the two power splitter outputs;

a first trimmer electrically coupled to the first circulator third port and a second trimmer electrically coupled to the second circulator third port;

a power combiner having two power combiner inputs and one power combiner output, wherein the first of the two power combiner inputs is electrically coupled to the first trimmer and the second of the two power combiner inputs is electrically coupled to the second trimmer; and

a third trimmer disposed between the second trimmer and the power combiner.

**3**. A system for improving port isolation of a three port circulator device, the system comprising:

a power splitter having a power splitter input and two power splitter outputs; a first circulator having a first circulator first port, a first circulator second port, and a first circulator third port, wherein the first circulator first port is electrically coupled to the first of the two power splitter outputs;

a second circulator having a second circulator first port, a second circulator second port, and a second circulator third port, wherein the second circulator first port is electrically coupled to the second of the two power splitter outputs;

a first trimmer electrically coupled to the first circulator third port and a second trimmer electrically coupled to the second circulator third port;

a power combiner having two power combiner inputs and one power combiner output, wherein the first of the two power combiner inputs is electrically coupled to the first trimmer and the second of the two power combiner inputs is electrically coupled to the second trimmer;

a fixed load electrically coupled to the first circulator second port;

further including a test load coupled to the second circulator second port, wherein the impedance of the test load is approximately equal to the impedance of the fixed load.

**4**. In a system including a power splitter having a power splitter input and two power splitter outputs; a first circulator having a first circulator first port, a first circulator second port, and a first circulator third port, wherein the first circulator first port is electrically coupled to the first of the two power splitter outputs; a second circulator having a second circulator first port, a second circulator second port, and a second circulator third port, wherein the second circulator first port is electrically coupled to the second of the two power splitter outputs; a first trimmer electrically coupled to the first circulator third port and a second trimmer electrically coupled to the second circulator third port; and a power combiner having two power combiner inputs and one power combiner output, wherein the first of the two power combiner inputs is electrically coupled to the first trimmer and the second of the two power combiner inputs is electrically coupled to the second trimmer;

a method for adjusting the first trimmer and the second trimmer to yield improved port isolation, the method comprising:

terminating a matching impedance fixed load and test load to the first circulator second port and the second circulator second port, respectively;

terminating test instrumentation at the power combiner output;

injecting a desired frequency signal into the input of the power splitter;

observing the strength of the signal at the power combiner output;

adjusting either of the first trimmer or the second trimmer to yield an attenuated desired frequency signal;

observing the strength of the attenuated desired frequency signal.

**5**. The method of claim **4**, wherein the adjusting is discontinued upon attenuating the desired frequency signal to −25 dB or less.

**6**. The method of claim **4**, wherein the adjusting is discontinued upon attenuating the desired frequency to −65 dB or less.

**7**. The method of claim **4** further including the steps of proving a trimmer tuner coupled to each of the first and second trimmers; proving a controller having a processor and a memory; wherein the processor is configured to inject the desired frequency, observe the strength of the strength of the attenuated desired frequency signal, and further adjust the trimmer tuners until a specified criterion is achieved.

**8**. The method of claim **7**, wherein the criterion is an attenuation threshold.

**9**. The method of claim **7**, wherein the criterion is an elapsed time.

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